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DAEDALEAN ASSOCIATES, INC.

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DAEDALEAN ASSOCIATES, Incorporated

(9) TECHNICAL REPORT

(6)

PRELIMINARY TESTING RESULTS FOR THE APPLICATION OF A NONDESTRUCTIVE EVALUATION TECHNIQUE UTILIZING THE PHENOMENON OF INTERNAL FRICTION FOR DETECTING CRACK FORMATION IN A SCALE MODEL OF AN OFFSHORE STRUCTURE.

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PRELIMINARY TESTING RESULTS FOR THE APPLICATION OF A NONDESTRUCTIVE EVALUATION TECHNIQUE UTILIZING THE PHENOMENON OF INTERNAL FRICTION FOR DETECTING CRACK FORMATION IN A SCALE MODEL OF AN OFFSHORE STRUCTURE

ABSTRACT

1.0 INTRODUCTION

The safety and reliability of offshore structures and critical components are becoming increasingly recognized as a major area requiring utilization of advanced technology for detecting and evaluating incipient crack formation by nondestructive evaluation. These operating structures and critical components are exposed to extreme oceanic environments including dynamic forces (wave loads, wind loads, ice loads, etc.); sea water corrosion; spray erosion; and wide fluctuations in temperature. Although adequate factors of safety and modern engineering practices are employed in designing and operating these structures, it is impossible to anticipate and evaluate properly all of the environmental factors in order to ensure the safety and reliability of the system.

Because of the complex interaction of the wide spectrum of environmental and material factors, it is imperative that inspection techniques be utilized. One method for system evaluation is to employ a suitable nondestructive evaluation (NDE) technique that would indicate impending material failure. Detecting incipient failure modes in

ABSTRACT

offshore structures and determining the remaining useful life of the critical components are important objectives in the application of any given nondestructive evaluation technique.

Moreover, as the operating depth requirements for offshore structures increase; a corresponding increase in sufficiency of design, fabrication, installation, operation, maintenance and material property requirements is necessitated. The complexity of the structures has required sophisticated design techniques and has established the need for utilizing high strength materials. The use of high strength materials for deep water structures increases the possibility of material failure modes including low temperature brittle fracture, stress corrosion cracking and hydrogen embrittlement of welded heat affected zones (HAZ). With the potential of structures utilizing high strength materials, there arises a need for suitable engineering requirements which include: 1) generating material design data for candidate high strength materials; 2) applying fracture safe design methods; 3) providing proper fabrication, welding and installation techniques; and 4) establishing reliable NDE techniques for quality assurance, acceptance and in-service inspection of modern offshore structures. Presently available nondestructive evaluation techniques cannot be readily used to predict the environmentally assisted fracture modes of offshore structures in-service. For this reason, a nondestructive evaluation technique

utilizing the phenomenon of internal friction damping of the material is being developed and evaluated for potential technical feasibility to offshore structure applications.

1.1 Internal Friction Damping

The internal friction is a result of the material's deviation from perfect elastic behavior even at small stress levels. Zener (1)* calls this behavior "anelasticity" of materials. Real solids are never perfectly elastic; therefore, some of their mechanical energy is always converted into heat. The various mechanisms by which this occurs are collectively termed as internal friction damping. Moreover, real solids exhibit a hysteresis loop whereby the stress-strain curve for decreasing stresses does not exactly retrace its upward path. Even though the offset in the magnitude of the hysteresis loop is negligible for static loading, it is an important factor in the material's dynamic response. In addition to hysteresis, engineering materials exhibit mechanical relaxation by an asymptotic increase in strain resulting from the sudden application of a fixed stress, and conversely, by an asymptotic relaxation in stress whenever they are suddenly strained. This mechanical relaxation has an associated relaxation time, the direct result of which is the severe attenuation of

* Numbers in parentheses refer to references at the end of this report.

vibrations whenever the imposed frequency has a period that approximates the relaxation time.

The mechanism by which the energy is dissipated may be any one of the following (2):

1. Relaxation by thermal diffusion
2. Relaxation by atomic diffusion
3. Relaxation by magnetic diffusion
4. Relaxation by ordered distributions
5. Relaxation of preferential distributions
6. Stress relaxation along previously formed slip bands
7. Stress relaxation across grain boundaries, and
8. Stress relaxation across twin interfaces.

For polycrystalline metals it was shown by Kê (3) that these relaxation mechanisms are the contribution factor for internal friction and, therefore, the mechanism of internal friction is described herein as a relaxation process. Moreover, these relaxation processes are govered by an associated characteristic time which corresponds to the peak frequency that is related to each relaxation process and is referenced to as the relaxation time. The relaxation time is associated with the diffusion coefficient and the specimen thickness (4).

1.2 Applications of Internal Damping

The phenomenon of internal damping of materials has been used to test authenticity of coins, the soundness of castings, the operating condition of railroad wheels, and the quality of musical instruments and glassware by listening to the tone and duration of sound (5,6,7). The study of internal damping has been a useful research tool in physical metallurgy; in vibration control of high speed missiles, planes, and vehicles; in fatigue of materials; and in the study of properties of metals and alloys from the standpoint of theoretical and analytical considerations. There are various technical terms to characterize this phenomenon: internal friction, logarithmic decrement, hysteresis constant, viscosity, elastic-phase constant, and specific damping capacity are a few.

From a resulting decay envelope, the frequency of oscillation and the specific damping capacity are easily determined (8, 9, 10). Moreover, the most direct method for defining internal damping is by the specific damping capacity. Precisely, the specific damping capacity, D, is given by:

$$D = \frac{\Delta W}{W} \qquad [1]$$

where:

$\frac{\Delta W}{W}$ is the energy dissipated in one cycle, and

W is the total energy of the cycle.

The specific damping capacity can be measured for a given frequency from the logarithmic decrement as follows.

$$\frac{\Delta W}{W} = 1 - e^{-2\alpha} \qquad [2]$$

where e is the base of natural logarithm and

$$\alpha = (1/N) \ln A_o/A_n \qquad [3]$$

where A_o is the amplitude of the reference cycle and A_n is the amplitude of the Nth cycle. Experimentally, the amplitudes are measured from the logarithmic decay curve and the A_o/A_n ratios are plotted on semilogarithm graph paper. The logarithm of the intercept is recorded, and the logarithmic decrement is obtained by dividing the intercept by the appropriate number of cycles. The specific damping capacity is obtained from the logarithmic decrement.

1.3 Objectives

1.3.1 Overall Objective

The overall objective of this research program is to identify the technology in utilizing the internal friction damping (IFD) in order to develop the necessary engineering design data and to demonstrate the associated instrumentation system for providing the nondestructive evaluation capability

1.3.2 Specific Objective

The current phase of the research program established the engineering base line design data required for the application of the internal friction damping nondestructive evaluation technique (IFD-NDE) to structural members and joints for typical offshore structural designs. The data was generated on a scale model offshore tower design under laboratory conditions. The purpose of this phase of the program was to address the technical feasibility of applying the equipment, technique, and software which would lead to a field application of the internal friction damping nondestructive evaluation technique to offshore structures.

1.4 Scope of the Program

In order to accomplish the overall objective of the program leading to the development of a prototype system for offshore towers and structures, quantitative measurements of failed members were made on a 1/14 scale model offshore tower under laboratory conditions. To achieve the objectives of this phase of the program, a complex structure, rather than a simple beam, was used to model the joints and welds for actual applications.

1.4.1 Equipment Requirements for Data Acquisition

The 1/14 scale model of an actual Gulf Oil Corporation offshore oil drilling structure as shown in Figure 1 was constructed for prototype evaluation of the internal friction damping NDE technique. The reliability and reproducibility for detecting failed members and joints was obtained by characterizing

the change in internal damping for various members, caused by structural cyclic fatigue. To achieve structural failure of joints and members characteristic of actual structural fatigue conditions, an electro-hydraulic system as shown in Figure 2 was used. The system consists of a hydraulic pump and directional valve which controlled the applicable force of a hydraulic cylinder. A solid state relay was used in conjunction with a gating system to control the directional valve. A harness was constructed to cause the hydraulic cylinder forces to be transmitted to the structure, characterizing waves, winds, and other fatigue conditions.

1.4.2 Internal Friction Damping Equipment

To determine the specific damping capacity for particular structural members, the NDE equipment was adapted and modified as shown in Figure 3. An oscillator was used to generate a sine wave which was input to the model tower via a mini-shaker. The output signal from the model tower was transmitted through a piezoelectric crystal accelerometer, then amplified and filtered before it was displayed on an oscilloscope. The oscilloscope display was then analyzed to determine the characteristic specific damping capacity.

1.4.3 Changes in Specific Damping Capacity

Changes in the dynamic response (internal friction), were portrayed by change in damping capacity, which indicated incipient crack detection. The change in the decay envelope for

crack detection is indicated in Figure 4. This figure compares the output decay curves for a failed member and a similar member which has not failed at an observed frequency of 1,500 Hz.

2.0 EXPERIMENTAL TECHNIQUES AND PROCEDURES

2.1 Equipment Description

The internal friction technique requires an input pulse and an associated output signal. The specific damping capacity is determined from the resultant decay curve of the output signal. The equipment needed to determine the damping capacity of the model offshore structure including the frequency spectrum analysis is included in Appendix A.

2.1.1 Transducer Location

The equipment was modified to coincide with the task of acquiring the engineering design data for the model structure. The modifications included the input electrical-mechanical loading device fixed in a single location with a mobile output. A "mini-shaker" was utilized as the input device because of the capability to transfer approximately 100% of its energy to the model offshore platform. The ability to couple a high percentage of input energy into the model platform reduced the total energy required for structural vibration. This reduced interference for the associated output signal. The output transducers were the accelerometer type (piezoelectric quartz crystals) which were mounted on the model platform using an attached magnet. The magnet attachment of the accelerometer provided multiple placement capability at numerous joints and members for generating and collecting the output data. The input location was selected above water level on the actual structure. The

output locations were selected to monitor the entire scale model offshore structure adequately. Certain output locations were fixed with the accelerometer rigidly attached (threaded fastener) to the structure. In these cases, the sensors were immovable so that a determination of the sensitivity of the output signal could be obtained. From the previous data analysis a low input voltage was chosen to prevent amplifier clipping as well as external vibrations that were caused in the pickup couplings. Moreover, the method of triggering was changed from the gate system to a manually activated trigger that would simultaneously end the input signal and trigger the oscilloscope display.

2.1.2 Spectrum Analysis

The addition of a level recorder to the NDE test system procedure added the frequency spectrum analysis capability. The frequency spectrum analysis made possible the identification of the major resonant peaks of each member and joint whereby the characteristics of each individual output could be analyzed. It also aided in defining the filter bandwidth size for each of the resonant peaks. The selection of the filter width was based on the bandwidth of the resonant peak. If the bandpass filters allowed a significantly larger bandwidth than the width of the output signal, external noise interference could be detected. For narrow filtering, the tuning of the input signal to the resonant frequency becomes

more critical. By investigating the frequency spectrum analysis graphs for failed versus non-failed joints, the frequency bands which had experienced significant changes in the internal friction damping could be located and analyzed. These particular frequencies proved most significant in detecting changes in decay values. The analysis of the frequency spectrum identified the dependence of the member location on the output frequency.

2.2 Literature Search of Offshore Structures

A literature search was conducted which included an investigation of the designs, uses, and classifications of offshore structures. The search dealt with an analysis of typical failures as well as the complexities encountered in structural integrity inspections. The in-house model was fabricated with actual structural material, construction, and assembly parameters in a similar fashion as an offshore tower. The model tower structure, derived from the overall literature search, was designed and constructed to 1/14 scale. The approximate height of the tower is 14 feet with the main columns 1-1/2 inches in diameter. The support bracing is 3/4 inches in diameter to maintain consistent scaling parameters. All material in the structure is steel pipe. The tower is divided into four repetitive sections. The redundant nature of the tower parallels actual offshore structures which are redundantly braced to maintain associated factors of safety.

2.2.1 Platform Fabrication

The upper platform which represents the operating surface on the actual offshore structure covers the entire area of the four vertical supports and is rigidly attached. The upper platform and all bracing members were welded to maintain structural integrity. A standard of quality assurance was maintained by close inspection of the joints using magnetic particle and dye penetrant techniques. The individual welded sections that comprise the supports and bracing system for the four main supports of the scale model offshore platform were contoured on each end before being welded into the structure. The curvature of the members matched the surface of the mating piece so that the contact between the two joined pieces was maximized. This procedure follows acceptable American Institute of Steel Construction (AISC) welding standards and simulates field construction of full size offshore towers.

2.3 Identification of Peak Frequencies

After the construction of the model structure had been completed, a frequency sweep (20 to 20,000 Hz) was made wherein specific resonances were investigated. Each major peak was analyzed.

Input and pickup locations were determined based on symmetry and reproducibility of the output signal. The input was placed in a position that was physically symmetric to the tower. Tests verified that a symmetric location produced less

interference and more reproducible results. The point chosen for the input was at the top of the structure. Pickup points to be tested were chosen so that all levels and quadrants of the structure would be physically represented along the vertical levels.

2.3.1 Electro-Hydraulic Fatiguing Apparatus

After the completion of the base line data for the model structure, an electro-hydraulic fatiguing apparatus (EH-FA) was designed and constructed. The fixed displacement pump was used because of the fluctuations in load requirements caused by the cyclic loading. The pump draws the hydraulic fluid from a 20 gallon reservoir. The fluid was pumped at a constant pressure and flow rate through two relief valves. The first relief valve actuated and controlled the required pressure. The second relief valve was spring actuated and allowed a faster reaction time and prevented pressure build-up throughout the system. The movement of the flow through the directional valve was controlled by a solid state relay which received its signal from the tone burst generator. A heat exchanger cooled the hydraulic fluid on a 1:1 basis with cooling water. Maximum allowable operating temperature for the pump and relief valves was 150°F. The hydraulic pressure in the system was converted to a loading capability through the hydraulic cylinder. The cylinder has a maximum stroke of 6 inches and a piston face area of 8.29 square inches. The

maximum pressure allowed by the system was approximately 3,000 psi.

2.3.2 Load Harness

The hydraulic cylinder was attached to a loading harness that transmitted the load from the cylinder to the scale model offshore platform member. The load cylinder was rigidly attached to a fixed-free rotational swing arm which was in turn rigidly braced to two of the main support struts of the platform. The stiffness of the loading harness was approximately twenty times the stiffness of the member being failed.

2.3.3 Platform Member Fatigue Failure

In order to fatigue a specific joint in the platform, an associated load force was applied to the midpoint of the member. The midpoint was chosen because of accessibility and simplicity of the stress transfer to the joint itself. From previous cyclic testing, a force applied to the midspan that would exert 85% of the material yield stress at the joint, was necessary. The maximum stress that would occur at the joint was the bending stress. The moment of inertia for this particular member has a value of 0.037 $in.^4$. The distance from the centroid to the extreme fiber is one-half of the diameter of 0.53 inches. The bending moment was derived for a beam supported at both ends and a concentrated load at the center. The supports were calculated as fixed/pinned. Using this support criteria, the maximum moment was taken from the bending

moment diagram. The maximum stress allowed was 85% of the yield strength (36 ksi), or 30.6 ksi which was produced by a 540 pound concentrated load.

The electro-hydraulic system was set to apply a load of 540 pounds in tension and compression to the midspan of the member. The cycle rate was set at approximately one (1) fatigue cycle each 0.75 seconds in order for the pump to regenerate the required force after each cycle.

The stress and location for loading a member that would produce failure in the joint or adjacent member was evaluated. From previous cyclic testing, a stress force that would achieve 85% of the yield stress could be used to fail the specimen in approximately 12,000 cycles.

3.0 TEST RESULTS

The procedure of structural fatigue cycling of the joint involved the assembly and dismantling of the loading harness. Before the harness was assembled on the model structure, a fatigue test was conducted on a structural element which simulated an element of the mode. This test was to assure a fail-safe cyclic loading procedure. Data collection and analysis was conducted on the model offshore tower at 1,000 cycle increments initially and later extended to 3,000 fatigue cycle increments. After each set of fatigue cycles, the cyclic loading system harness was dismantled and data was collected for the various pickup or input locations. After failure had occurred, the member would be removed and a new identical member was fabricated and welded into place, preceded by careful inspection.

3.1 Test Data

The specific damping capacity measurements were recorded along with the total number of cyclic load applications. The data from the particular joint tested demonstrated that the resonant frequency of the specific point evaluated must be utilized in order to define the incipient failure of the associated member or joint. The specific damping capacity results are listed in Table 1 along with the various cyclic load applications and the individual locations where inputs and outputs were located. Comparisons of the data indicate that for the

resonant frequency of the member, an increase is noticed as the member experiences an increased number of cyclic load applications.

3.1.1 Discussion of Test Results

The resonant frequency of member 30-31 was 2263 Hz. At this frequency, the incipient failure data increased dramatically. Specific damping capacity values did not change for this member at other frequencies regardless of the input location. Similar results were obtained for joint 30.

Fatiguing member 30-31 by means of the electro-hydraulic loading apparatus produced a microcrack at joint 30 after 10,000 cycles. A microcrack was also produced in member 30-31 at the midspan after 10,000 cycles. Total failure (crack through the wall thickness) occurred at 13,500 cycles. For joint 30, specific frequencies were input for 670 Hz, 2215 Hz, 2325 Hz and 2506 Hz. A four-fold increase in the specific damping capacity was noted in the associated decay curve at 2215 Hz. The damping capacity increased from approximately 15 to 64. The damping of 64 occurred at 9,900 cycles. Similar data is presented in Table 1 for member 30-31. Input frequencies of 500 Hz, 2025 Hz and 2260 Hz were related to specific damping capacity measurements. At 2260 Hz, the damping capacity increased approximately four-fold. The initial value of 12 for the specific damping capacity increased to 55 just prior to failure.

The initial failure test data listed in Table 1 demonstrated the sensitivity of the specific damping capacity to variations in frequency at the failure point. The analysis of the data indicated that the prediction of incipient failure with specific damping capacity was frequency dependent for the complex model offshore platform.

3.1.2 Incorporation of Digital Processor

For this reason, a digital processor by Digital Equipment Corporation (DEC) was evaluated and incorporated into the IFD-NDE system. Several hardware manufacturers were evaluated, and the DEC PDP 11/34 was selected as the digital processing system most suited for use with the internal friction damping nondestructive evaluation technique. More information on how the selection was made is included in a later section of this report.

A frequency spectrum analyzer function enabled the specific damping capacity measurements to be obtained as a function of frequency and implemented the analysis of data in defining the incipient failure of a joint or structural member of the scale model offshore platform. The output from the frequency spectrum analyzer is shown in Figure 5. The equipment package included a frequency spectrum analyzer in the form of a digital processor that utilized a fast fourier transform (FFT) software program and a graphics terminal for display. The computer assisted digital processor was capable

of performing the frequency spectrum analysis on the complex output from the model offshore platform for an individual member and joint. The resulting frequency selected for use in determining the specific damping capacity was obtained from the FFT program and utilized in the automatic acquisition of the specific damping capacity data. Numerous configurations of digital processing equipment were evaluated with the results included in Appendix B.

4.0 INITIAL PROGRAM CONCLUSIONS

This report concludes that the reliability and reproducibility of the dynamic response of materials as measured by the specific damping capacity as a function of the load cycle history can be used to determine incipient crack formation when proper base line data has been established. It has been concluded in earlier reports (11,12,13,14) that the IFD-NDE technique is a viable method for predicting impending failure caused by fatigue cracking. Within the framework of this program and based on the main objective as stated in an earlier section, the following conclusions are warranted.

1. The specific damping capacity is reproducible for measurements made on various members of the 1/14 scale model offshore tower.

2. The necessary instrumentation system for automatically obtaining specific damping capacity measurements for a model offshore tower has been demonstrated. This capability includes a fast fourier transform performed on the output signal that will identify the frequency dependent specific damping capacity which in turn will predict incipient crack formation.

3. Various measurements made by two independent operators are reliable and reproducible (at the 99% confidence level) for a given single measurement comparison within similar sets of data.

4. The internal friction damping nondestructive evaluation technique has predicted incipient crack formation at a welded joint for a member that was fatigue loaded for a specific number of cycles. Prediction of failure at the welded joint was frequency dependent for the signal input location chosen.

5. The prediction of incipient failure and crack formation can be made utilizing the specific damping capacity measurements derived from the internal friction outputs of the 1/14 scale model offshore tower.

5.0 PROGRAM RECOMMENDATIONS

The completion of this phase of the program as indicated by the test results from the 1/14 scale model offshore tower provides for the following specific recommendations regarding the effect of the specific damping capacity on the detection and analysis of crack formation.

1. It is recommended that the dependence of the specific damping capacity on the variation in the input for various members of the offshore platform be identified.

2. It is recommended that the extent to which the specific damping capacity would change as a result of the removal of an actual brace or member of the platform be characterized.

3. It is recommended that the capability of analyzing multiple frequency outputs be included in the operational system. The ability to reduce and analyze data from multiple frequency outputs is necessary to define the onset of incipient crack propagation. The output from the analysis defines the incipient crack propagation point when the proper frequency is utilized in the analysis. Proper input frequency and output frequency selection is necessary to ensure early crack detection. The recommendation to

include the multiple frequency analysis output capability will fully automate the internal friction damping nondestructive evaluation technique.

REFERENCES

1. Zener, C., "Internal Friction in Solids, Theory of Internal Friction in Reeds," Physical Review, Vol. 52, p. 230, 1937.

2. Zener, C., "Elasticity and Anelasticity of Metals," The University of Chicago Press, Chicago, 1948.

3. Ke', T. S., "Experimental Evidence of the Viscous Behavior of Grain Boundaries in Metals," Physical Review, Vol. 71, p. 533, 1947.

4. Hochrein, A. A., Jr. and Thiruvengadam, A. P., "The Dynamic Response of Metals in Evaluating Stress Corosion Cracking," Journal of Testing and Evaluation, JTEVA, Vol. 2, No. 5., September 1974, pp. 370-377.

5. Koehler, J. S., "The Influence of Dislocations and Impurities on the Damping and the Elastic Constants of Metal Crystals," Imperfections in Nearly Perfect Crystals, Edited by W. Shockley, John Wiley & Sons, Inc., New York, New York, p. 191, 1962.

6. Heidenreich, R. D., and Shockley, W., "Dislocation Geometry," Conference on the Strength of Solids, University of Bristol England Physical Society, London, 1948.

7. Orwan, I. E., "Mechanism of Viscous Flow in Solids," Proceedings West of Scotland Iron and Steel Institute, 1947.

8. Jenson, J. W., "Damping Capacity - Its Measurements and Significance," Bureau of Mines Report of Investigation 5441, United States Department of the Interior, 1959.

9. Ke', T. S., "Stress Relaxation Across Grain Boundaries in Metals," Physical Review, Vol. 72, p. 41, 1947.

10. King, R., Cahn, R. W., and Chalmers, B., "Mechanical Behavior of Crystal Boundaries in Metals," Nature, Vol. 161, p. 682, 1948.

11. Thiruvengadam, A. P. and Hochrein, A. A., Jr., "The Development of a Nondestructive Evaluation Technique for Acceptance, Certification and Requalification of Pressure Vessels Utilizing the Phenomenon of Internal Friction in Materials," DAI Report No. AT-7537-01-FR, August 1975.

12. Cameron, J. M., Daniel, C., III, Thiruvengadam, A. P., and Hochrein, A. A., Jr., "The Application of a Nondestructive Evaluation Technique for Hyperbaric Pressure Vessels Utilizing the Phenomenon of Internal Friction in Materials," DAI Report No. JC-7639-01-FR, November 1976.

13. Envent, F., Thiruvengadam, A. P., and Hochrein, A. A., Jr., "A Feasibility Study of Applying Internal Friction Measurement as a Nondestructive Acceptance Test for Deep Ocean Submersible Pressure Hulls," DAI Report No. FE-7447-F, July 1975.

14. Yeager, L. L., Thiruvengadam, A. P. and Hochrein, A. A., Jr., "The Application of a Nondestructive Evaluation Technique for Hyperbaric Pressure Vessels Utilizing the Phenomenon of Internal Friction in Materials," DAI Report No. LY-7639-02-TA, October 1977.

MEMBER 30-31 FAILURE

(LOCATION OF FAILURE-MIDPOINT MEMBER 30-31)

INPUT LOCATION	PICKUP LOCATION	FREQ.	CYCLES			FAILURE
			0	3000	6000	9900
			SPECIFIC DAMPING CAPACITY			
MDPT Member 24-31	Joint 30	2325	19.9	21.9	24.7	27.9
MDPT Member 30-39	MDPT Member 30-31	2263	12.3	15.1	16.9	55.9
MDPT Member 30-39	Joint 30	671	17.8		23.8	17.5
Joint 30	MDPT Member 30-31	499	11.3	12.8	13.0	12.7
Joint 30	MDPT Member 30-31 (Accel. Para. to member)	2027	40.3	48.9	47.6	53.5
MDPT Member 30-31	Joint 30	2506	13.5	22.2	14.9	33.1
MDPT Member 30-31	Joint 30	2215	15.6	19.4	13.8	64.8

TABLE 1 - TYPICAL OUTPUT VALUES OF THE SPECIFIC DAMPING CAPACITY LISTED FOR A MEMBER AND A JOINT OF THE SCALE MODEL OFFSHORE PLATFORM FOR THE VARIOUS NUMBER OF CYCLIC LOAD CYCLES

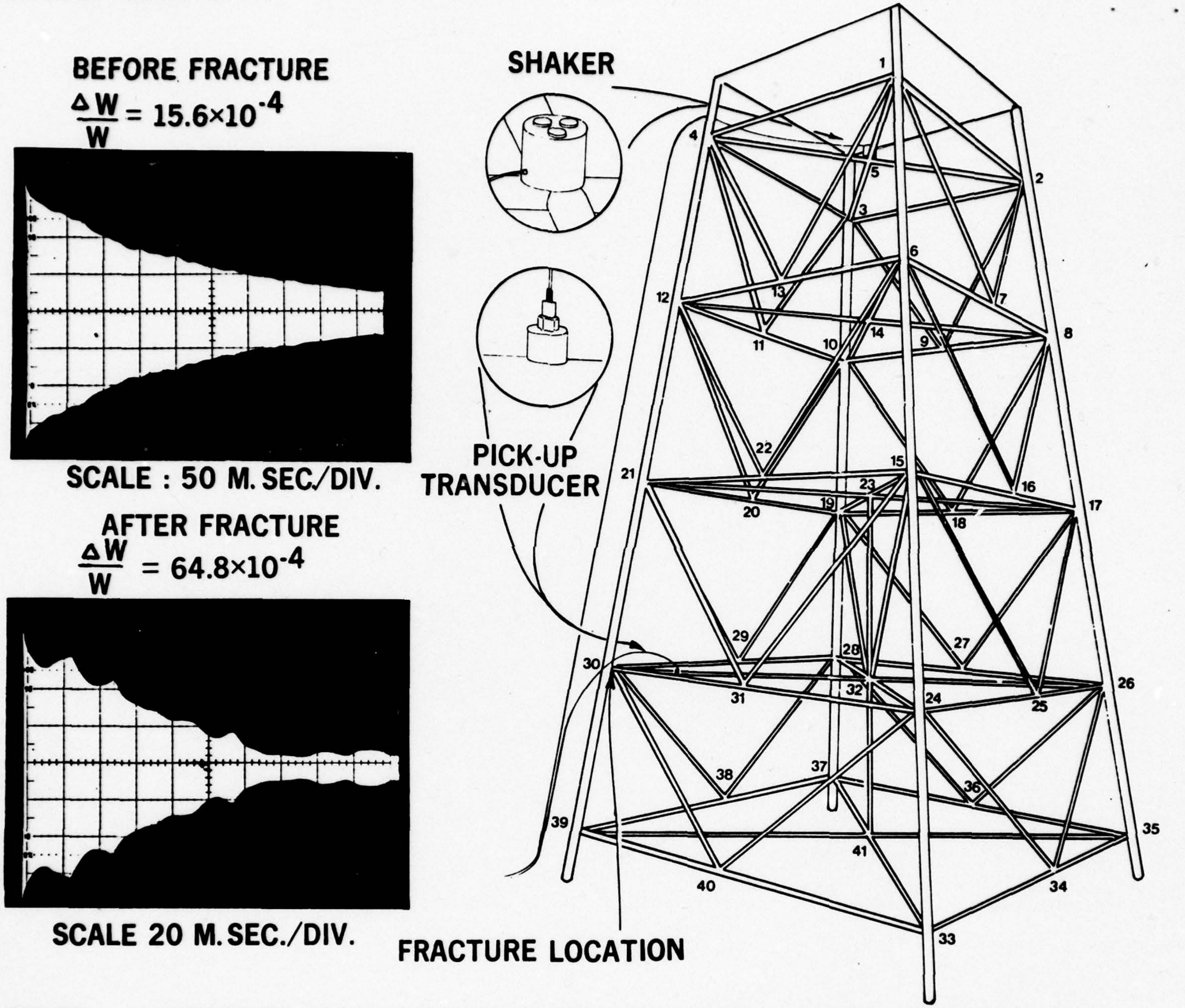


FIGURE 1 ILLUSTRATION OF 1/14 SCALE MODEL OFF SHORE TOWER SHOWING INPUT AND OUTPUT TRANSDUCERS THEIR TYPICAL LOCATIONS, AND REPRESENTATIVE DECAY CURVES BEFORE AND AFTER FRACTURE OCCURRED IN MEMBER 30-31 AT JOINT 30

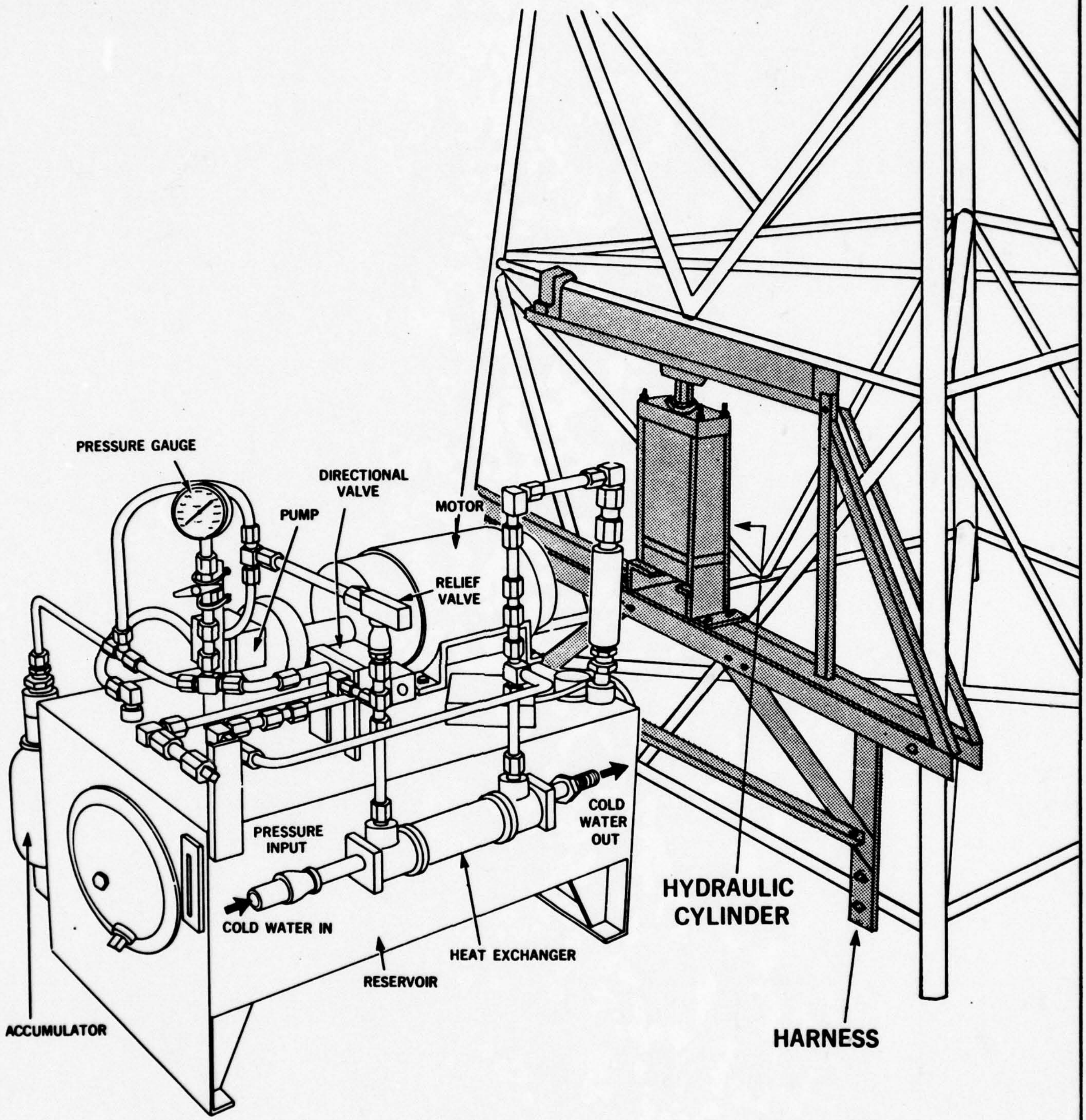


FIGURE 2 GRAPHICAL REPRESENTATION OF THE ELECTRO-HYDRAULIC LOADING APPARATUS INCLUDING THE LOADING TRANSFER HARNESS

DAEDALEAN ASSOCIATES, Inc.

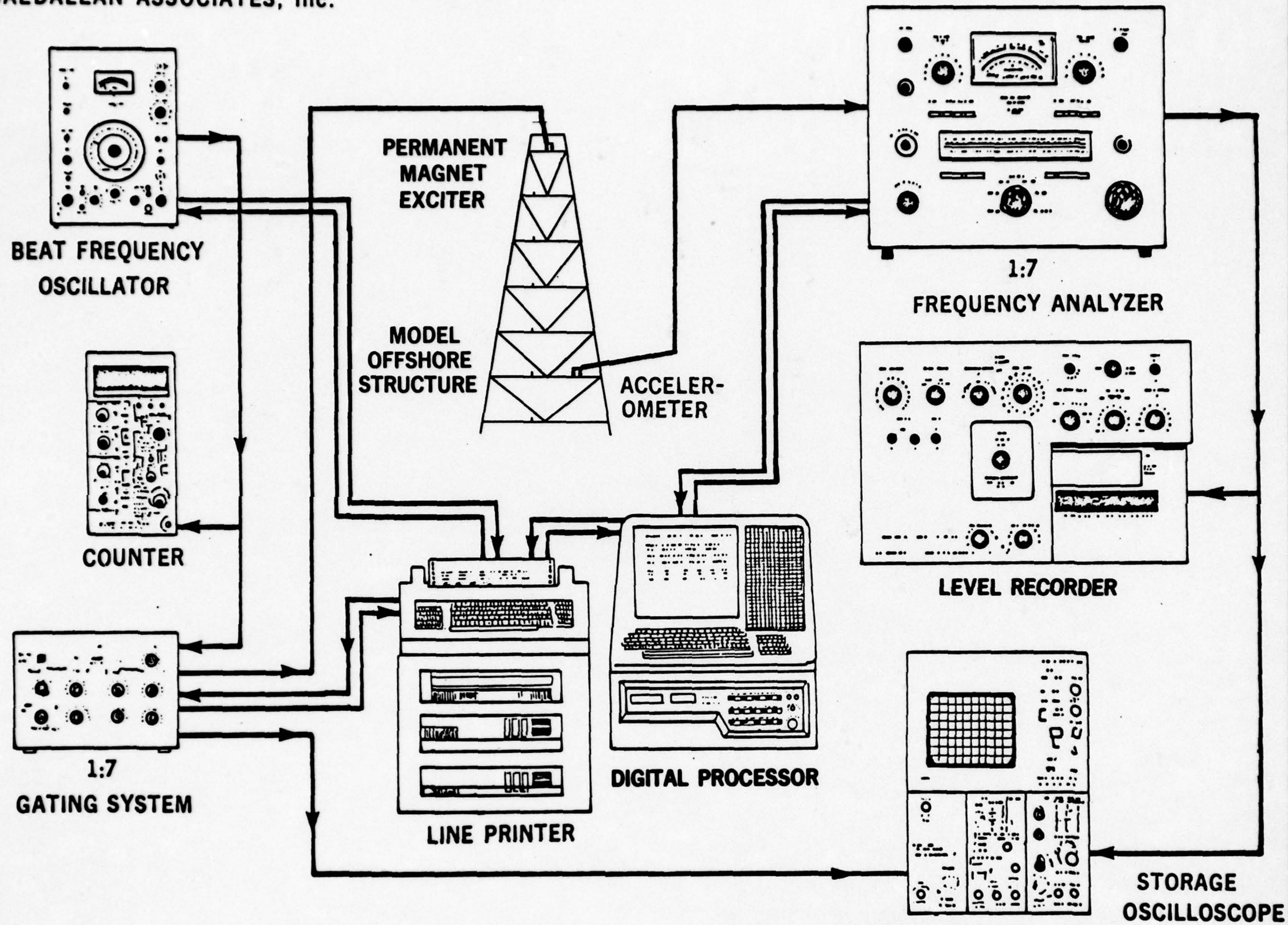
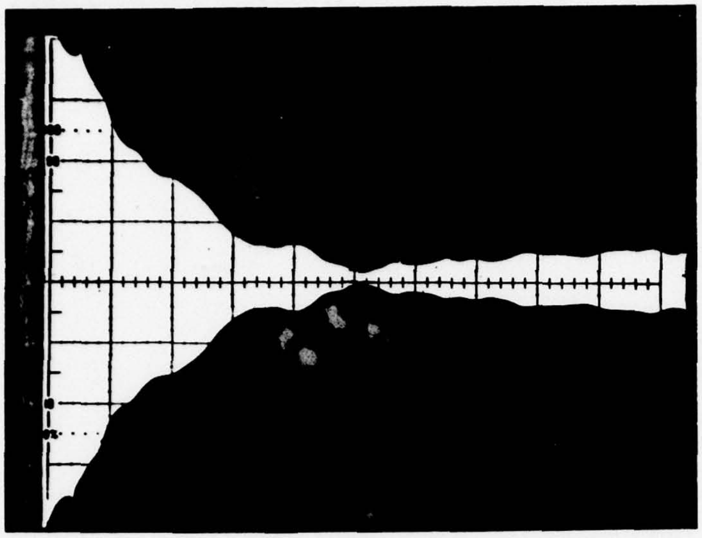
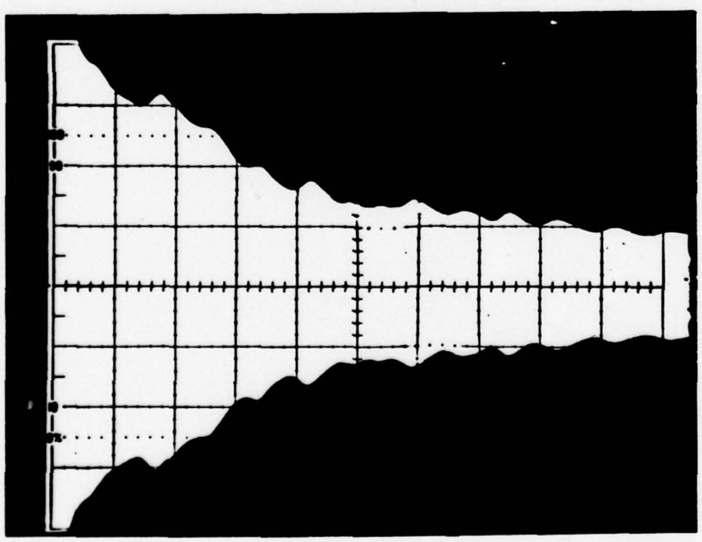


FIGURE 3 DIAGRAM OF TEST APPARATUS UTILIZED IN SPECIFIC DAMPING CAPACITY MEASUREMENTS SHOWING THE INTERFACE WITH A CENTRAL PROCESSING UNIT AND INPUT/OUTPUT CONTROLLER



FAILED MEMBER 30-31 FREQUENCY OBSERVED = 1500 HZ

1500 HZ



SIMILAR NOT FAILED MEMBER FREQUENCY OBSERVED = 1500 HZ

FIGURE 4 COMPARISON OF DECAY CURVES FOR A FAILED MEMBER AND A SIMILAR MEMBER WHICH HAS NOT FAILED.

AMPLITUDE VALUE FOR FREQUENCY DOMAIN CURSOR

	X = 18	166.0156 HERTZ	POWER = 1841.064
CURSOR:	X = 19	175.7812 HERTZ	POWER = 33100.648
	X = 20	185.5469 HERTZ	POWER = 27807.393

FREQUENCY SPECTRUM ANALYSIS

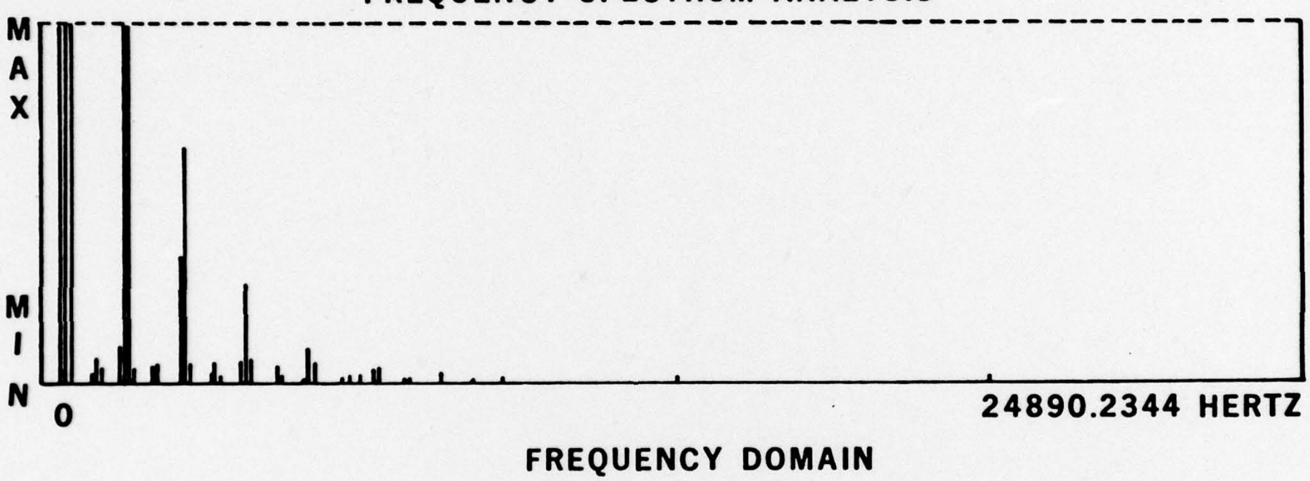


FIGURE 5 ILLUSTRATION OF THE OUTPUT FROM THE FAST FOURIER TRANSFORM (FFT) PROGRAM THAT ILLUSTRATES THE AMPLITUDE OF THE RESPONSE AS A FUNCTION OF THE FREQUENCY SPECTRUM

APPENDIX A

EXPERIMENTAL APPARATUS

INTRODUCTION

The internal friction technique requires an input pulse and an associated output signal. The specific damping capacity is determined from the resultant decay curve of the output signal. This appendix describes the equipment necessary to determine the specific damping capacity.

EQUIPMENT

The NDE equipment needed to determine the specific damping capacity of the model offshore structure is as follows:

a. Beat Frequency Oscillator - The application of the NDE technique requires an input of periodic excitation pulses. This input is achieved by utilizing a B & K type 1022 Beat Frequency Oscillator. The B & K 1022 oscillator supplies a periodic signal at a multitude of single frequencies in the range of 20 Hz to 20,000 Hz.

b. Tone Burst Generator - A general Radio type 1396-B was used to gate the signal from the oscillator into a series of discrete pulses. The Tone Burst Generator

controls the pulse duration and the time interval between pulses.

c. Permanent Magnet Vibration Exciter - A B & K type 4810 "Mini-Shaker" converted the electric signals received from the Tone Burst Generator into mechanical vibrations. The "Mini-Shaker" was directly attached to the 1/14 model offshore tower.

d. Accelerometer - The vibrational response of the tower was measured by an accelerometer. The accelerometer, a B & K 4334, consisted of a magnetic coupler attached to a piezoelectric quartz crystal that converted the vibrational response of the tower to an electric signal.

e. Audio Frequency Analyzer - The output signal from the accelerometer was then filtered and amplified by an Audio Frequency Analyzer, a B & K type 2107 in this case. The Frequency Analyzer amplified and filtered the signal to remove any unwanted transient noise that was present. The output signal from the Frequency Analyzer was displayed with the use of a level recorder and a storage oscilloscope.

f. Display - A storage oscilloscope, Tektronix Type 564 and a level recorder was used to display the output from the Frequency Analyzer. Conventional methods of

analyzing the data utilized the display of these instruments.

The digital processing unit with the input/output capability is used to control the lab peripherals of the original NDE system and is also used to acquire and analyze the data. The Digital Equipment Corporation (DEC) 11L34-HA processor with DEC LPA11-K memory and options serves as the total processing and control unit. Included in the package is a graphics terminal which eliminates the need of constant use of the storage oscilloscope and level recorder. These instruments are for supplying hard copy from the initial test. If the intermediate data is not required in hard copy form, the output from the line printer of the DEC 11/34 serves as the final reduced hard copy. The necessary equipment to perform the frequency spectrum analysis is included in the following description.

The Digital Equipment Corporation PDP 11/34 mini-computer consists of the following:

a. PDP-11/34

The PDP-11/34 is a mid-size microprogrammed processor. The CPU is compact and contained on two circuit boards. This provides greater flexibility during later system expansion by making additional chassis space available.

The Memory Management is an advanced memory extension, relocation and protection feature. The Memory Management

provides extended memory space from 28K to 124K words, plus segmentation and effective protection of memory segments in in multi-user environments.

Self-test Diagnostic Routines are automatically executed every time the processor is powered up, the console emulator routine is initiated, or the bootstrap routine is initiated.

Operator front panel with built-in CPU console emulator allows control from any terminal without the need for the conventional front panel with display lights and switches.

Automatic bootstrap loader allows system restart from a variety of peripheral devices without manual switch toggling or key-pad operations.

The central processor contains eight general registers which can be used for a variety of purposes. The registers can be used as accumulators, index register, auto increment or auto decrement registers, as well as stack pointers for temporary storage of data. The instruction complement uses the flexibility of the general purpose registers to provide hard-wired instructions.

The Extended Instruction Set (EIS) provides the capability of performing hardware fixed-point arithmetic and allows direct implementation of multiply, divide, and multiple shifting.

The FP11-A floating point is an arithmetic processor which fits integrally into the PDP-11/34 central processor. It per-

forms all floating-point arithmetic operations and converts data between integer and floating-point formats. This option provides flexible addressing in addition to single and double precision (32 or 64 bit) floating-point modes, and it is fully program compatible with all double precision PDP-11 floating-point processor options.

b. DECpack Disk

This disk subsystem includes a disk controller and two drives. It is a complete mass storage system for random access data storage. One drive utilizes a removable disk cartridge with 2.4 million bytes (8 bit bytes) capacity. The other drive utilizes a fixed disk drive with an additional 4.8 million bytes.

The DECpack features a transfer time of 11.1 microseconds/word. Average total access time on a disk drive is 70 milliseconds. All data transfers are DMA (direct memory access).

c. VT55 Graphic Terminal

The VT55 is an on-line interactive CRT terminal that offers waveform graphics capability. Two graphs of 512 (maximum) data points each can be displayed with a screen resolution of 512 points (x) by 236 points (y). Cursors (20 point vertical lines) are available (one per data point) to facilitate data editing and graph generation. In addition, the VT55 allows simultaneous display of any combination of text and graphics. The VT55

supplies a hard copy reproduction of the display screen for both characters and graphs.

The VT55 can hold up to 1,920 characters in 24 lines of an 80 character-per-line matrix.

d. ADK11-KT, Real-Time Analog Data Acquisition

This real-time Analog Data Acquisition Package consists of the necessary logic and listed hardware for interfacing to laboratory analog instrumentation. The package contains a 12 bit, 16 channel, single ended (or 8 channel differential) analog-to-digital converter, a dual programmable real-time clock, cable, and a distribution panel to provide a complete instrumentation interface package.

e. AD11-K Analog-to-Digital (A/D) Converter

The 12 bit A/D converter can be switch selected to operate as a 16 channel, single ended, 16 channel pseudo-differential or 8 channel true differential A/D converter. The A/D converter will convert an analog voltage from within one of the specified input ranges of ± 5V, ± 5.12V, ± 10V, ± 10.24V, 0 to 10V, or 0 to 10.24V to a digital number for processing. These input ranges are jumper selectable. The A/D converter contains an input multiplexer, sample and hold, 12 bit successive approximation A/S converter and UNIBUS interface logic. The A/D converter can be started in one of three ways: under program control, on overflow of the programmable clock, or from external input. This versatility allows the adaption of the package to most individual applications.

f. AA11-K D/A Converter System

The AA11-K is a 4 channel, 12 bit digital-to-analog converter (DAC). It has the control logic for displays such as the Tektronix 602, 604 display scopes and 611, 613 storage scopes. The four DAC channels are controlled by four independent registers directly addressable from the UNIBUS. This allows complete flexibility in programming the output of the DAC for a variety of applications. The 4 channel, 12 bit D/A converter can be used with point plot display, analog X/Y or chart recorders, set point controller, programmable power supply and signal generators.

g. DR11-KT 16 Bit Digital I/O Interface

The DR11-KT general device interface is an integral logic module which forms a self-contained digital input/output interface between the DECLAB-11/34 UNIBUS and a user's peripheral. The general purpose interface performs all of the necessary tasks to communicate with the processor is so that the user may easily interface a device or devices.

Under program control, the general purpose interface permits bidirectional parallel transfer of up to 16 bits of information between the UNIBUS and a user's device or another general purpose interface are fused and have recoverable over-voltage protection.

Various options, which are hardward-selected by the user, are available for data input. Data can either be read off a

user's device directly onto the UNIBUS or through the input register. The input register bits are transitionally set by its respective input line.

h. IEEE 488-Bus Interface

An IEEE 488 standard bus interface acts in conjunction with the PDP-11/34A as a system controller, allowing control of instrumentation which includes IEEE 488 interface capability.

i. LPA11-K

The LPA11-K is a direct memory access (DMA) controller for DIGITAL's laboratory data acquisition I/O devices. It is a fast microprocessor subsystem. The LPA11-K allows analog data acquisition rates up to 150,000 samples per second and is designed for applications requiring concurrent data acquisition and data reduction at high rates. Operation system support is provided under RT-11 and RSX11-M.

The LPA11-K allows multiple users to simultaneously control analog-to-digital converters (ADC), digital-to-analog converters (DAC), real-time clocks, digital input and digital output (digital I/O). Interaction with these peripherals is performed by the microprocessors; therefore, the host PDP-11 is freed from the overhead of the interrupt service routines normally associated with these devices.

To meet a variety of applications the LPA11-K operates in two distinct modes, dedicated and multirequest. In dedicated mode the LPA11-K performs high speed data acquisition from

analog-to-digital converters for a single user. In multi-request mode the LPA11-K allows up to eight simultaneous users to perform data acquisition at independent rates from any one of the supported device types.

Maintainability is an important part of the LPA11-K subsystem. Standard diagnostic capability is coupled with microcode dedicated to fault identification. The LPA11-K subsystem has the capability of diagnosing faults within the laboratory I/O peripherals. Request verification and error reporting are provided during data acquisition.

j. Languages for the DEC11/34

The RT-11 software as supplied by Digital Equipment Corp. is the operating language for the digital processor. Fortran IV and BASIC are included in the system. The Fortran IV software includes a full set of subroutines that supports real-time, reading analog signals, controlling a graphic terminal, and controlling I/O hardware. The last feature is the most important one as it allows the user to automatically control other peripherals such as the frequency analyzer through the I/O.

APPENDIX B

DIGITAL PROCESSING EQUIPMENT

INTRODUCTION

Numerous configurations of digital processing equipment have been evaluated as a means of assisting the Internal Friction Damping (IFD) Nondestructive Evaluation (NDE) technique in predicting incipient failure. The systems which were evaluated in this program are listed along with the results of the evaluations.

a. Texas Instrument

A Texas Instrument SR52 programmable calculator and a P-100 printer were evaluated as the digital processor for the IFD-NDE technique. The calculator was sufficient for data reduction but was not capable of being programmed for the more complex data analysis techniques. There was no interface capability with the IFD-NDE equipment which would mean that the data could not be acquired by the processor automatically. This manual step of transferring the data and the lack of data analysis eliminated this system as the automated digital processing system.

b. Bruel & Kjaer (B & K)

The B & K IFD-NDE equipment as it is presently configured could be used as a supporting system for a digital processor.

The B & K equipment can be interfaced with a digital processor that could automatically acquire the data, analyze it, store the reduced data and retrieve it at a later time for comparative purposes. The B & K equipment would supplement the digital processor with its ability to record the log decrement decay of the material being tested. The B & K equipment has no capability to reduce the data on its own.

c. Nicolet Scientific Corp.

The Nicolet Model 660 digital oscilloscope with built-in microprocessor was evaluated as a digital processing system for use with other NDE equipment. The Nicolet system was capable of analyzing signals at very low frequencies, but did not have an analog to digital converter that could transform the signal fast enough at higher (above 1,000 Hz) frequencies. Since most signals are analyzed between 20 Hz and 20,000 Hz, this Nicolet system becomes impractical.

d. Hewlitt Packard (HP)

The H. P. 9825A programmable desk-top calculator was evaluated for suitability as the digital processor to be used in conjunction with the present IFD-NDE equipment. Its main disadvantage was the slow analog-to-digital converter, its lack of memory storage, and the resultant loss in high frequency capability. The H. P. system would require that additional storage be made available to handle most IFD-NDE testing. This additional cost in memory and storage brings the con-

figured price of this system very close to the mini-computer range.

The following systems are all of the mini-computer variety and were evaluated differently based on their superiority to the less sophisticated digital programmable calculators. The mini-computers all have the capability of intelligently controlling lab peripherals that include the present NDE equipment. The storage, analysis and retrieval capability of these systems are very fast. The systems evaluated are:

a. Varian V77
b. Data General Eclipse S/130
c. IBM Series I (4900)
d. Honeywell
e. Digital Equipment Corp. PDP 11/34

All of these systems were evaluated with the same basic configuration including peripherals. The basic system consisted of a central processor with 64K of memory, an analog-to-digital converter, an input/output controller, addressable memory storage, controlling package, a terminal, and a line printer. The system was also configured to include operating software and scientific subroutines. The selection of the digital processor was based on the ability of the various mentioned systems to perform the necessary NDE functions. The automatic acquisition of data was an essential feature that each system could perform. The final choice was based on price, options

that were included at no extra charge, and the fact that the systems manufacturer that was selected has a history of successes primarily in the scientific field of computer assistance. Digital Equipment Corporation's PDP 11/34 was selected as the final configuration that would assist the present equipment in conducting internal friction damping nondestructive evaluations.

As a result of the investigation of the various systems, the Digital Equipment Corporation PDP 11/34 system was found to best suit the requirements of the IFD-NDE technique. The Digital 11/34 system has many capabilities that the lesser systems cannot match such as the fast A to D and the main storage. The major advantages that the system has over the four other mini-computers include:

a. Inclusion of options that Varian, IBM, Data General and Honeywell do not include such as bidirectional parallel transfers, intelligent control system, and a fast line printer.

b. Digital Equipment Corporation has exclusively built computers for scientific applications that routinely include companies for the same price.

c. The Digital Equipment Corporation has demonstrated the portability of the system which would be most suitable for use in the field.